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Patentanmeldung Nr. Patent application No. Demande de brevet n°

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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
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High force density linear electric motor

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High force density linear electric motor

The present invention relates to a linear electric motor or actuator, comprising a movable part consisting of a soft-magnetic core which supports a set of electrically conductive windings, which movable part is slidably supported, generally by using air-bearings, by a rail structure which is provided with at least one set of permanent magnets distributed in its longitudinal direction along its periphery and which produce magnetic fields which, via an air gap, co-operate with the the set of windings.

Linear electric motors of the type described above are already known and extensively used for various purposes, especially as actuators, for a long period of time. The movable part of such known motors is provided with a core consisting of a stack of laminated soft-magnetic steel plates. The stacked configuration of the steel plates reduces on the one hand the electrical losses in the core but, on the other hand, provides the core with only a 2D flux carrying capability, i.e. only flux conduction in the thin plates and not in the transverse direction.

Although these electric motors function very well and are extensively used for a considerable time already they have the disadvantage that, due to their core construction, they are rather heavy and voluminous with respect to the force they are able to provide.

It is an object of the present invention to provide a linear electric motor which is lighter and smaller and has a reduced volume compared with the known standard linear motors.

In order to achieve this object the linear electric motor or actuator according to the invention is characterized in that the soft-magnetic core of the movable part is made of soft-magnetic composite material, whereas the electrically conductive windings are wound around the periphery of the core substantially perpendicular to the central line of the core, and at least two sets of magnets are provided on the rail in its longitudinal direction

in such a way that the at least two sets of magnets are arranged under different angles around the core.

It has to be noted here that the soft-magnetic composite material used for the core of the inventive linear motor or actuator, is already known for a number of years and has e.g. been disclosed in "Permanent-Magnet Machines with Powdered Iron Cores and Prepressed Windings" by Alan G. Jack; Barrie C. Mecrow; Philip G. Dickinson; Dawn Stephenson; James S. Burdess; Neville Fawcett and J.T. Evans in IEEE Transactions on Industrial Applications, Vol.36, No.4, July/August 2000.

Although the use of soft-magnet composite materials in permanent-magnet machines has been described in this publication, nothing has been disclosed about the constructive advantages such materials could have for linear motors or actuators and also no particular configuration of linear motors using soft-magnetic composite materials have been suggested.

The idea on which the present invention is based proposes to make use of the three dimensional {3D}-flux carrying capability of the soft-magnetic composite material in such a way, that the amount of force producing surface of the linear motor is increased without further increase in the amount of copper used for the windings and consequently without increase in the losses produced in the machine.

According to the invention, the core may have a longitudinal form with a sectional shape in the form of a square, a rectangle ,a triangle or a circle. The co-operating rail should then, of course, have a corresponding cross-sectional shape and the sets of permanent magnets are arranged on that rail in such a way, that they surround at least partly the core and the windings. In that way the magnetic fields of the permanent magnets are directed under different angels onto the core so that the surface of interaction between the magnets and the windings is substantially increased. This inventive arrangement of the magnets around the core is made possible due to the 3D-flux carrying capability of the soft-magnetic composite core material.

A further embodiment of the linear electric motor/actuator according to the invention is characterized in that the rail is provided with cooling means, which extend in its longitudinal direction and are in heat exchanging contact with the core and windings over a part of their periphery.

According to a further embodiment of the inventive motor, it is also possible to provide the core with internal cooling channels. In that case even more outer

surface of the core and windings structure remains available for co-operation with sets of permanent magnets.

According to another embodiment of the motor according to the invention, the core is provided with circumferential slots in which the windings are located.

Further advantages and characteristics of the present invention will be explained in the following detailed description of the invention under reference to the accompanying drawings, in which:

Figs. 1a and 1b show schematically, and not to scale, a side elevation and a cross-section, respectively, of a conventional linear electric motor.

Figs. 2a and 2b show schematically, and not to scale, a side and front elevation, respectively, of a linear electric motor according to the present invention.

Figs. 3 and 4 show a schematic representation of the sectional shape of the moving part of a linear electric motor according to the present invention, with a circular and a triangular shape, respectively.

Fig. 5 shows the core of a linear electric motor according to the present invention, which is provided with circumferential slots in which the windings can be placed.

Fig. 6 shows the moving parts of a conventional and a linear motor according to the invention, both motors providing similar power.

Figs. 1a and 1b show a conventional linear electric motor with a moving part 1 consisting of a core 2 comprising a stack of laminated steel plates 3. The plates 3 are provided with teeth 4 around which windings 5 of electrically conductive wires are placed. The movable part 1 is slidable in a rail 6 in which permanent magnets 7 are taken up which, via an air-gap 8, co-operate with the windings 5.

A problem with such a conventional construction resides in the fact that the laminated core is only able to carry magnetic flux along the steel plates and not in a transverse direction, which constitutes a severe limitation for the area of the force producing surface. A further problem resides in the fact that, from a constructional point of view, it is very difficult to cool the moving part efficiently in order to achieve an acceptable working temperature. Also the end windings 9 in this embodiment do not contribute to the force production.

Figs. 2a and 2b show a similar linear electric motor which also comprises a moving part 21 and a rail 26, but now the movable part consists of a core 22 made of a soft-magnetic composite material and the windings 25 are wound directly around the core 22 substantially perpendicular to the central line of the core. The rail 26 has a U-shaped cross-section with a bottom wall 28 and two side walls 29, both the bottom wall and the two side walls carry each a set of permanent magnets 27, 30 and 31 which, via their associated air-gaps, co-operate with the windings 25 on the core 22. It will be clear that in this way all three of the sides of the core contribute to the force generation of the motor. If desired, this can still be increased by closing the top side of the rail and also positioning a set of permanent magnets on this side so that all sides of the moving part and the rail serve as a force producing surface.

The arrangement of two, three or even four sets of permanent magnets along the respective sides of the movable part is made possible due to the fact that the soft-magnetic material used for the core 22 has 3D-flux carrying capability. In this way the force density of the linear electric motor is increased, compared with a conventional linear motor.

In Fig. 6 a movable part of a conventional linear electric motor is denoted with reference numeral 61, and the movable part of a linear motor according to the invention generating the same force is denoted by reference numeral 62. It will be immediately clear that the size of the moving part 62 according to the invention is about half the size of the conventional moving part. From this, it will be clear that the size and volume of linear electric motors according to the present invention can be much smaller and lighter than conventional motors providing the same force.

As schematically shown in Fig. 2b, the top side of the rail 26 is carrying a cooling channel 32 which is in good heat-exchanging contact with the moving part 21 and its core 22 and windings 25. With such a cooling channel, heat can be extracted very efficiently from the machine so that its operational temperature will be kept within acceptable limits.

Instead of using one of the sides of the movable part for heat exchanging contact with cooling channels as in the embodiment according to Fig. 2b, it is also possible to provide the core 22 with internal cooling channels so that in such case the upper side can also be used as a force producing surface. The only thing to be done is locating a permanent magnet on this side which co-operates with the windings.

Further possible embodiments of the linear electric motor according to the invention are schematically shown in Figs. 3 and 4. In the embodiment according to Fig. 3, the transverse sectional shape is circular. This is in fact a very advantageous shape. The

circular core 42 can be easily manufactured and the windings 45 can easily, and without sharp bends, be wound around the circular core. The permanent magnets 47 are in this case ring-magnets, which can either completely surround the core 42 and windings 45, or the construction can have the shape as shown in the drawing, so that on the flat top surface there can be arranged a cooling channel in heat-exchanging contact with the core and windings.

In Fig.4 it is shown schematically that the linear electric motor according to the invention can, if so desired, also have a triangular sectional shape or a partly triangular shape in which the top part of the triangle is taken away, so that the top surface 60 of the core can be provided with cooling elements.

Finally, in Fig. 5 it is shown how the core 21 of soft-magnetic composite material can be provided with circumferential slots 50 in which the electrically conductive windings can be located. Although this makes the shape of the core a little bit more complicated, it reduces the size and the weight of the core and thus of the whole motor considerably. In this case the teeth 51 can also be provided with teeth-tops 52 as shown schematically in Fig. 5b, in order to reduce parasitic effects.

Moving parts in linear motors tend to produce parasitic force components, which is called "cogging". In the linear motor according to the present invention it is possible to achieve zero cogging by means of extending the soft magnetic composite material of the core at the ends thereof in relation with the magnetic field distribution. The length of the end extensions is a function of the pole pitch of the magnet.

From the above description, it will be evident that the present invention provides a linear electric motor having a number of surprising advantages over conventional linear motors. Although some configurations of the inventive motor have been described herein, it will be appreciated that many alternatives are possible within the scope of the appended claims.

CLAIMS:

1. Linear electric motor or actuator, comprising a movable part consisting of a soft-magnetic core which supports a set of electrically conductive windings, which movable part is slidably supported by a rail which is provided with at least one set of permanent magnets, distributed in its longitudinal direction along its periphery, and which produce magnetic fields which, via an air, gap co-operate with the set of windings, characterized in that the soft- magnetic core is made of soft-magnetic composite material, whereas said electrically conductive windings are wound around the periphery of the core substantially perpendicular to the central line thereof, and at least two sets of permanent magnets are arranged along its periphery in its longitudinal direction in such a way that the at least two sets of magnets are arranged under different angles around said core.

2. Linear electric motor according to claim 1, characterized in that the cross-section of said core of soft-magnetic composite material has a square or rectangular shape, and in that the sets of permanent magnets are positioned along at least two, but preferably three, sides thereof.

3. Linear electric motor according to claim 1, characterised in that the cross-section of said core of soft-magnetic composite material has a substantially circular shape and said set of permanent magnets are formed by ring magnets which in transverse direction surround a substantial part of the circumference of the core.

4. Linear electric motor according to one or more of the preceding claims, characterised in that said rail is provided with cooling means which extend in the longitudinal direction of the rail and are in heat-exchanging contact with said core and windings over a part of their surface.

5. Linear electric motor according to one or more of the preceding claims, characterised in that said core is provided with internal cooling channels.

6. Linear electric motor according to one or more of the preceding claims, characterized in that said core is provided with circumferential slots in which said windings may be located.

ABSTRACT:

Linear electric motor or actuator, comprising a movable part (21) consisting of a soft-magnetic core (22) which supports a set of electrically conductive windings (25), which movable part is slidably supported by a rail (26) which is provided with at least one set of permanent magnets (27, 30, 31) extending in its longitudinal direction along its periphery. ~~The~~ magnets (27, 30, 31) produce a magnetic field that via an air gap co-operates with the set of windings (27, 30, 31). The soft-magnetic core (22) of the movable part (21) is made of soft-magnetic composite material. The electrically conductive windings (25) are wound around the periphery of the core (21) substantially perpendicular to the central line thereof, and at least two sets of magnets (27, 30, 31) are arranged along its periphery in such a way, that the at least two sets of magnets (27, 30, 31) are arranged under different angles around the core (22).

Figs. 2a, 2b

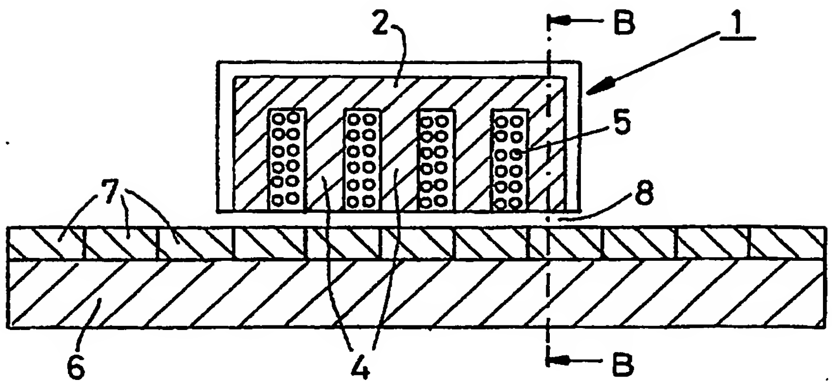

FIG.1a

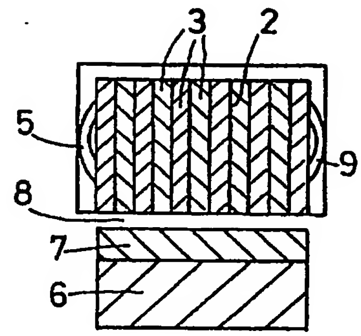

FIG.1b

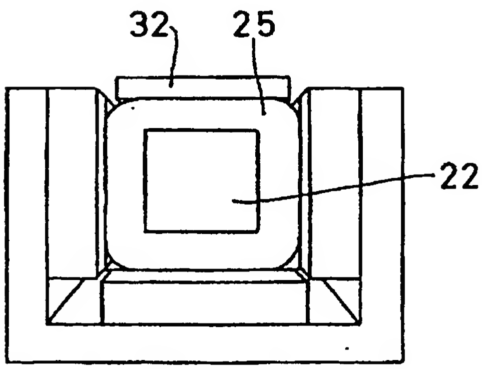

FIG.2a

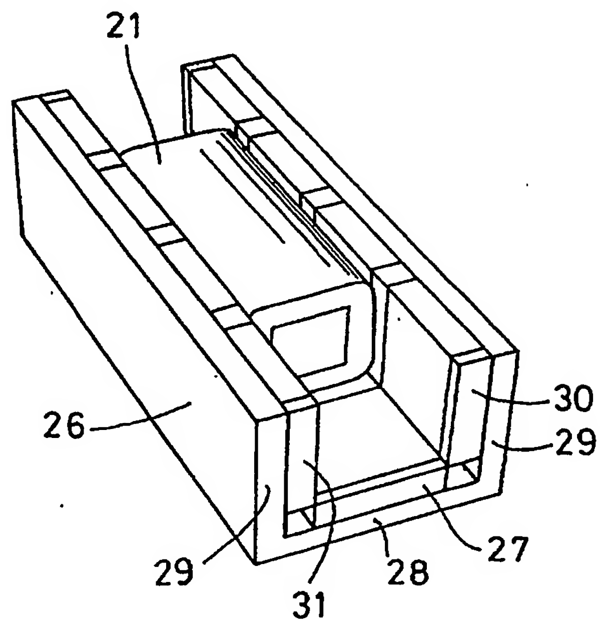

FIG.2b

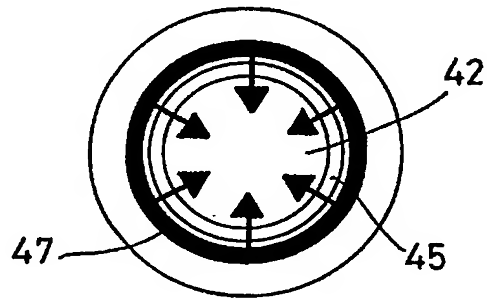

FIG.3

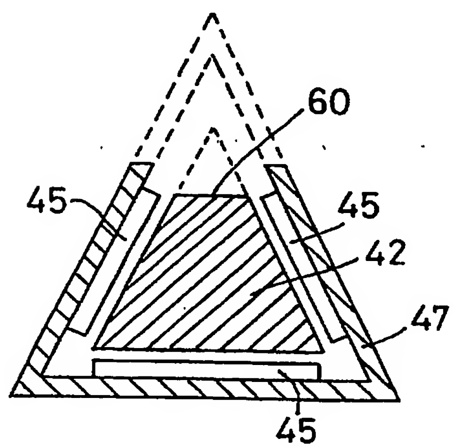

FIG.4

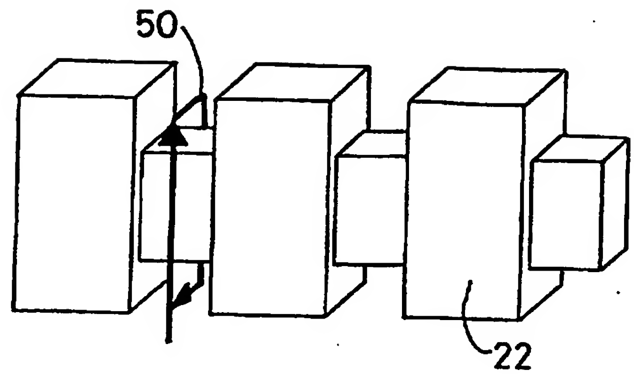

FIG.5a

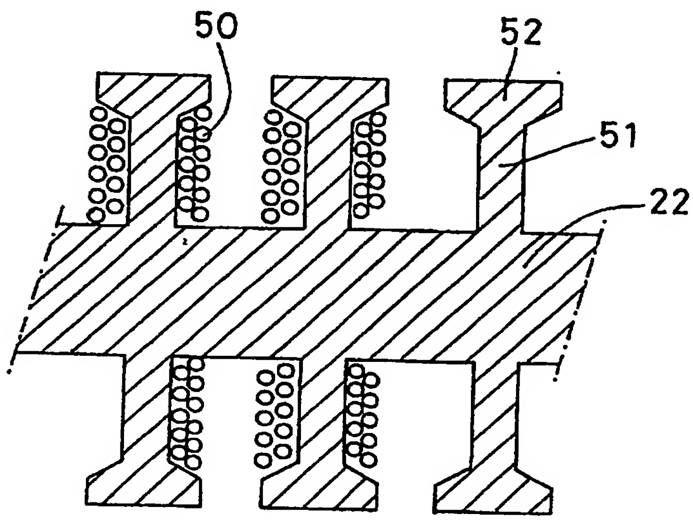

FIG.5b

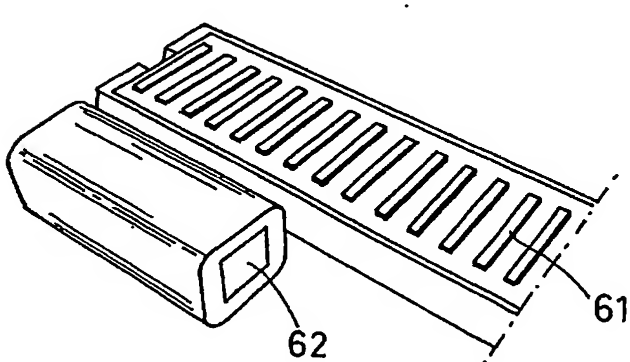

FIG.6